Measurement of photons via conversion pairs with PHENIX at RHIC

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Outline

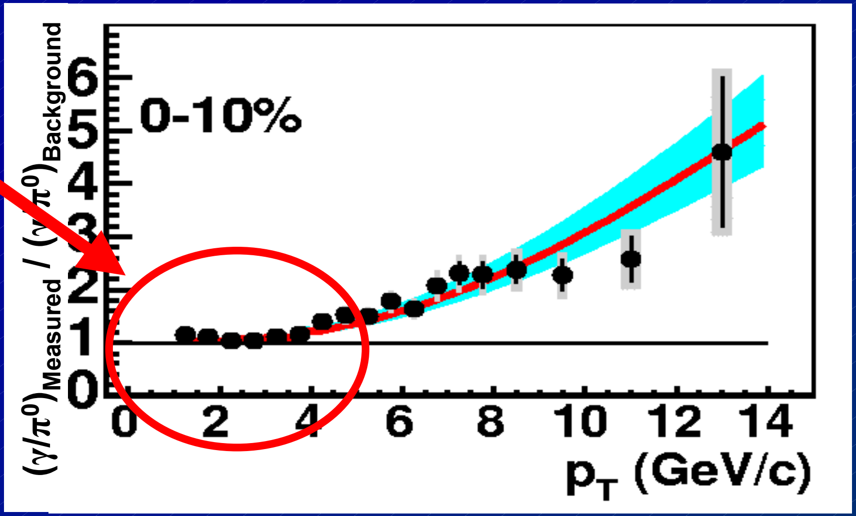
- Motivation – possibility to measure photons at low p_T
- Technique – photon conversions in beam pipe
  - Invariant mass spectra of e^+e^- pairs
  - Conversion pair properties
  - Extraction of conversion pairs
  - Reconstruct π^0 with this “tagged” photon sample
  - Comparison with simulated hadronic photon spectrum
- Summary

Direct Photons

- Carry information about initial temperature
- Do not interact strongly → unaffected by final state effects
- Emitted from QGP like black body radiation
- Production mechanisms:
  - quark-gluon Compton scattering: $qg \rightarrow \gamma q$
  - quark-antiquark annihilation: $q\bar{q} \rightarrow \gamma g$
  - Bremsstrahlung
- Other sources of direct photons are initial hard scattering processes

Measurements of direct photons in heavy ion collisions

- Thermal photons predicted to dominate photon spectrum at 1-3 GeV/c
- Direct measurement of photons in this energy region impaired by:
  - Neutral hadron contamination
  - Energy resolution in π^0 reconstruction



S.S. Adler et al., Phys. Rev. Lett. **94**, 232301 (2005)

The idea: photon conversions

- Clean photon sample: e^+e^- pairs from beampipe conversion
- Why?
  clear photon identification
  Very good momentum resolution of charged tracks at low p_T
- Procedure
  - Identify conversion photons in the beampipe
  - Tag π^0 by pairing electron pairs from conversions with photons in EMCal
  - Do the same in simulations
- Double Ratio: efficiencies and acceptance corrections cancel out

Double ratio: technique and advantages

ε_{pair} = e^+e^- pair efficiency

a_{pair} = e^+e^- pair acceptance

f = conditional probability of having a photon in the acceptance, once you already have the e^+e^- pair in the acceptance

DATA

$$N_\gamma^{incl}(p_T) = \cancel{\varepsilon}_{pair}\,\cancel{a}_{pair}\,\gamma^{incl}(p_T)$$

$$N_\gamma^{\pi^0 tag}(p_T) = \cancel{\varepsilon}_{pair}\,\cancel{a}_{pair}\,\varepsilon_\gamma\,\cancel{f}\,\gamma^{\pi^0}(p_T)$$

$\varepsilon_\gamma = \gamma$ efficiency

SIMULATION

$$N_\gamma^{hadron}(p_T) = \cancel{a}_{pair}\,\gamma^{hadr}(p_T)$$

$$N_\gamma^{\pi^0 tag}(p_T) = \cancel{a}_{pair}\,\cancel{f}\,\gamma^{\pi^0}(p_T)$$

in simulations all efficiency are 100%

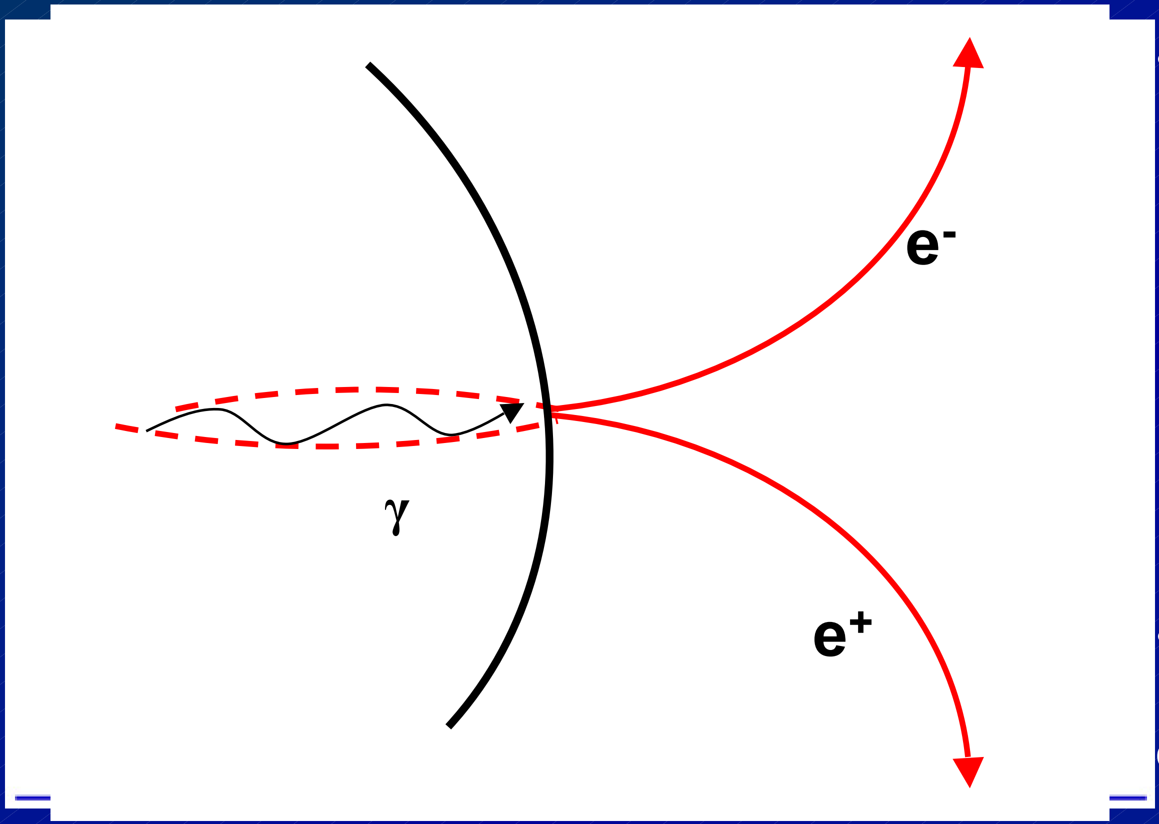
$$\frac{\left(N_\gamma^{incl}(p_T)/N_\gamma^{\pi^0 tag}\right)_{data}}{\left(N_\gamma^{hadr}(p_T)/N_\gamma^{\pi^0 tag}\right)_{sim}} = \frac{\gamma_{incl}}{\varepsilon_\gamma \gamma_{hadr}}$$

DOUBLE RATIO

$$\Rightarrow \frac{\gamma_{incl}}{\gamma_{hadr}} = \varepsilon_\gamma \frac{\left(N_\gamma^{incl}(p_T)/N_\gamma^{\pi^0 tag}\right)_{data}}{\left(N_\gamma^{hadr}(p_T)/N_\gamma^{\pi^0 tag}\right)_{sim}}$$

everything cancels out except for $\varepsilon_\gamma \sim 98\%$
→ minimal systematics

The PHENIX experiment

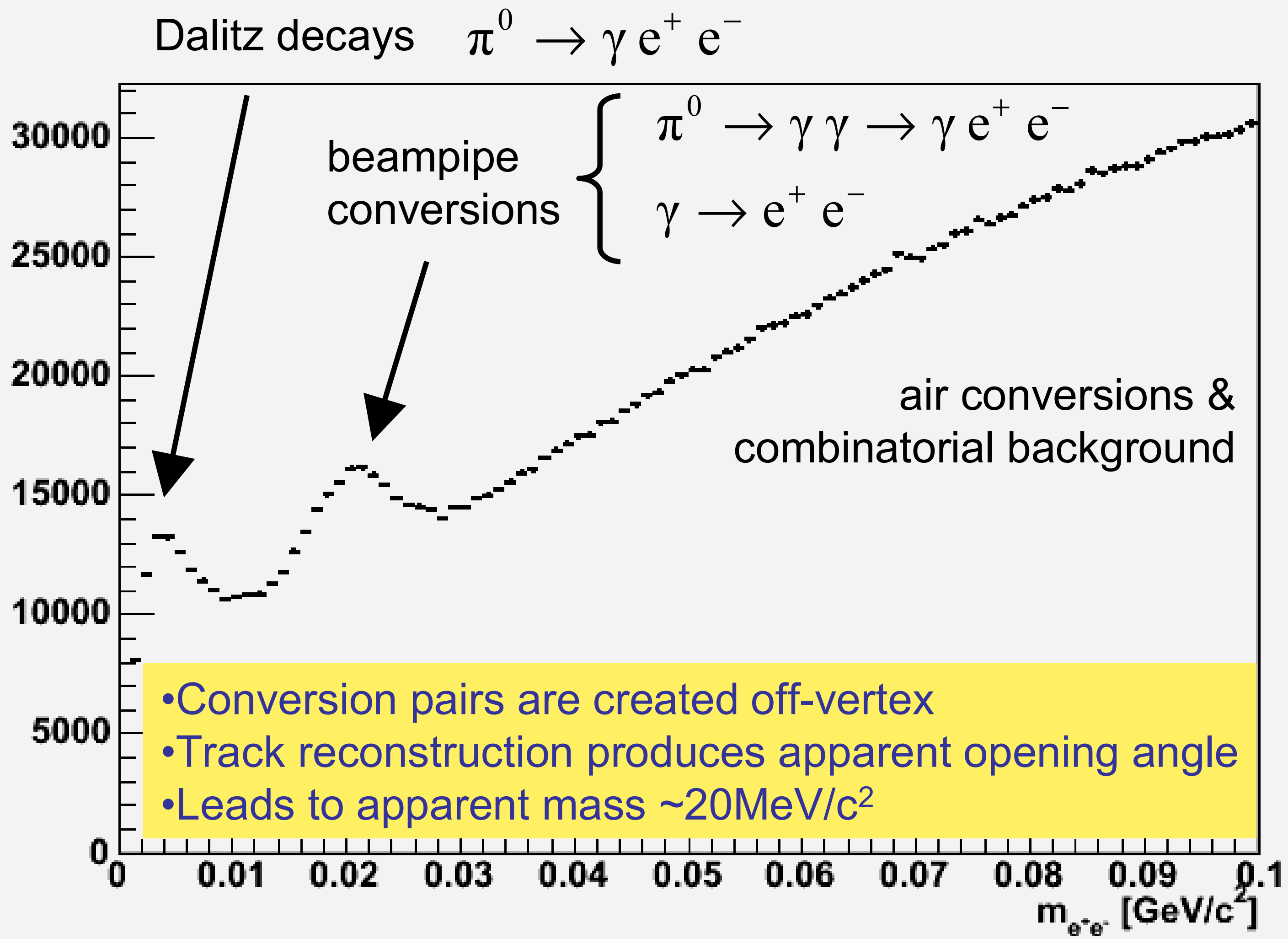


•electrons:
- •momentum reconstruction (1% resolution)
- •particle ID: RICH (loose cuts because clean signature of conversion peak)
- •same or opposite arms: different pT acceptance

•photons:
EmCal (loose cuts → high efficiency ~ 98%)

track reconstruction assumes vertex in the interaction point
→ conversion at radius r≠0: e+e- pairs 'acquire' an opening angle
→ they acquire an invariant mass $m = \int B\,dl \sim r > 0$
if r=4 cm (beampipe) m =20 MeV

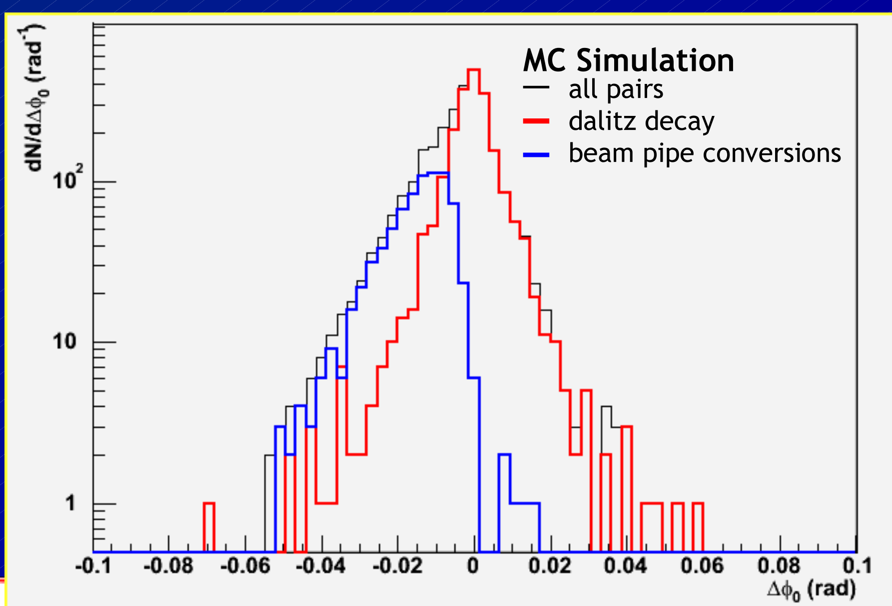
Invariant e^+e^- mass spectrum of Run 4 Au+Au: $\sqrt{s_{NN}} = 200\,\mathrm{GeV}$

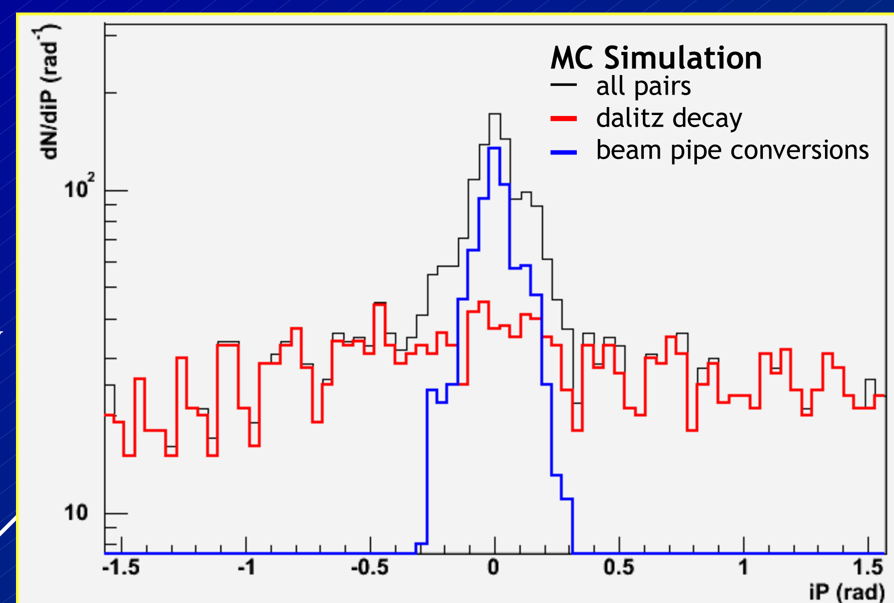


- Conversion pairs are created off-vertex
- Track reconstruction produces apparent opening angle
- Leads to apparent mass ~20MeV/c^2

Pair properties

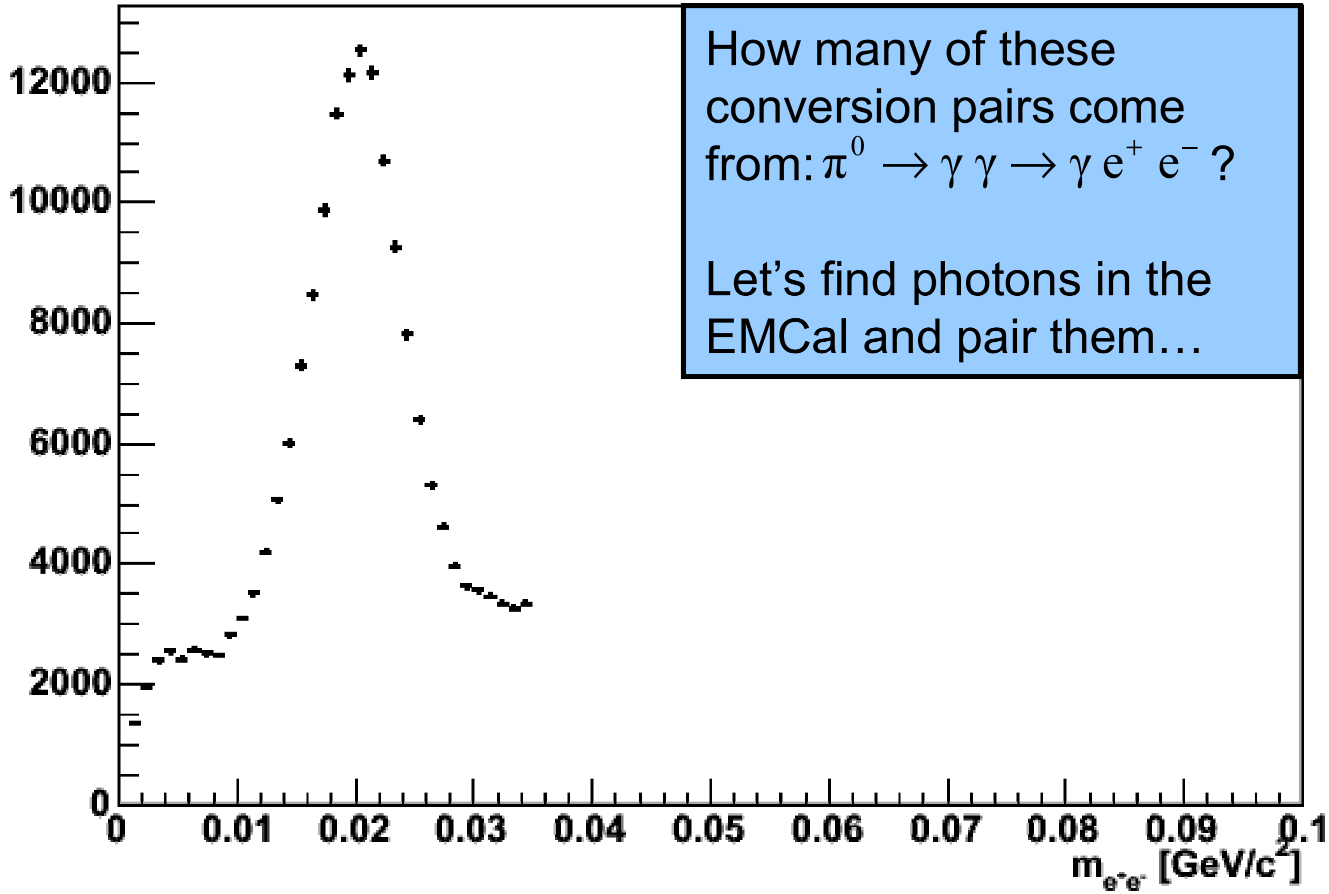
- Dalitz decays have a real opening angle due to the π^0 mass
- Conversion pairs have small intrinsic opening angle
  - magnetic field produces opening of the pair in azimuth direction $\Delta\varphi_0 = \varphi_0(e^-) - \varphi_0(e^+) < 0$
  - orientation perpendicular to the magnetic field





Beam pipe conversions

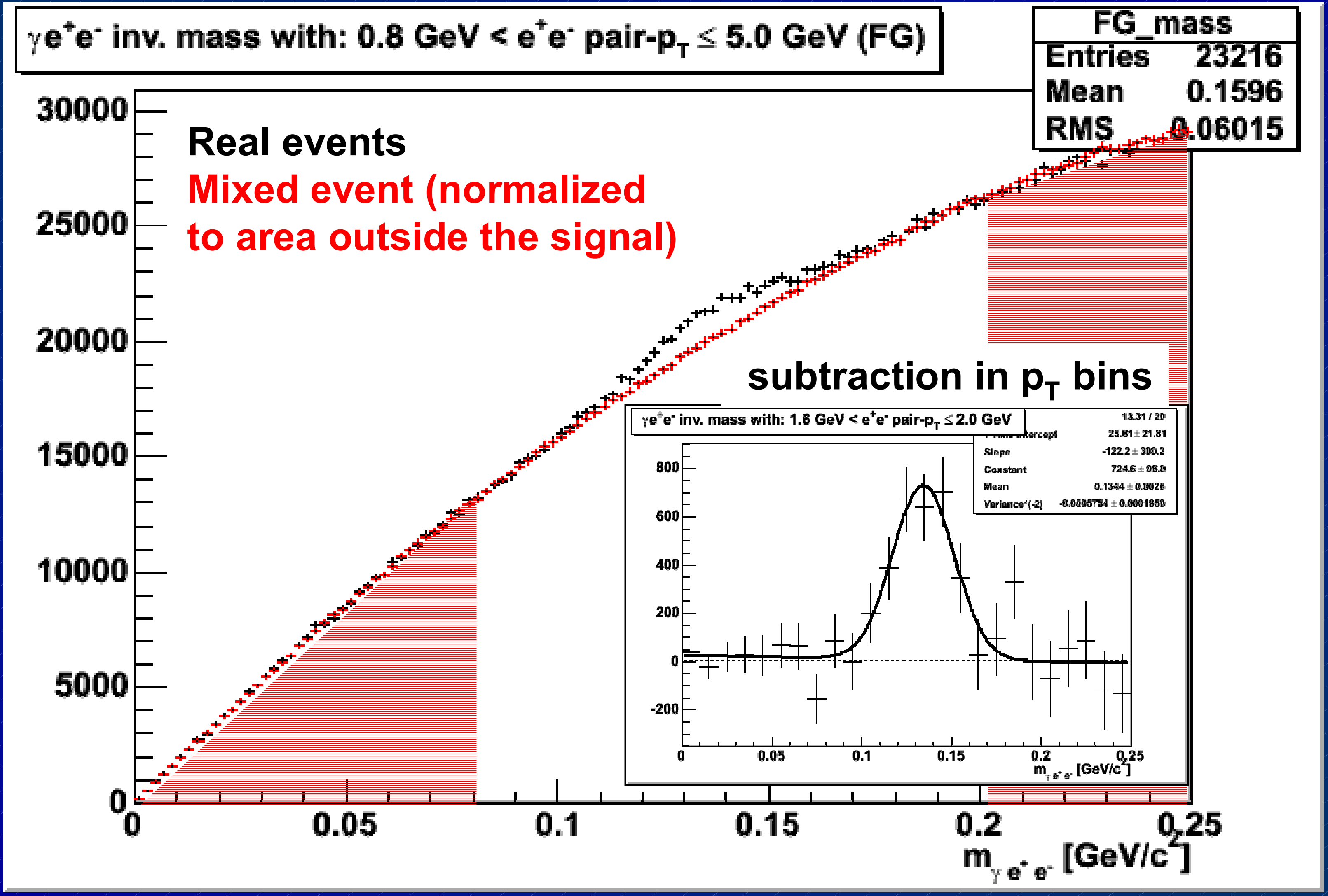
Invariant mass spectrum after applying pair cuts



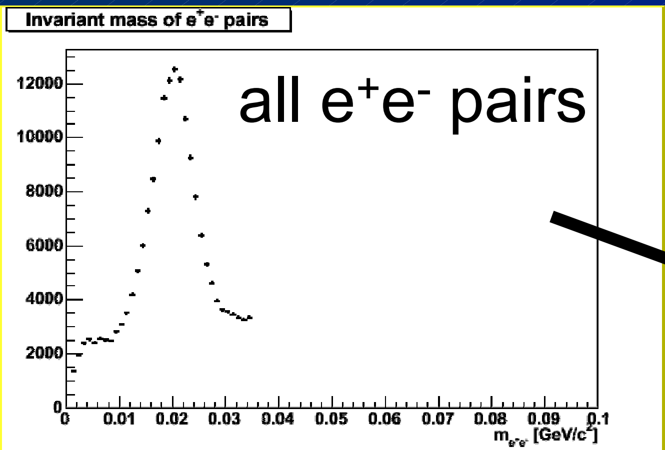
How many of these conversion pairs come from: $\pi^0 \rightarrow \gamma\,\gamma \rightarrow \gamma\, e^+\, e^-$?

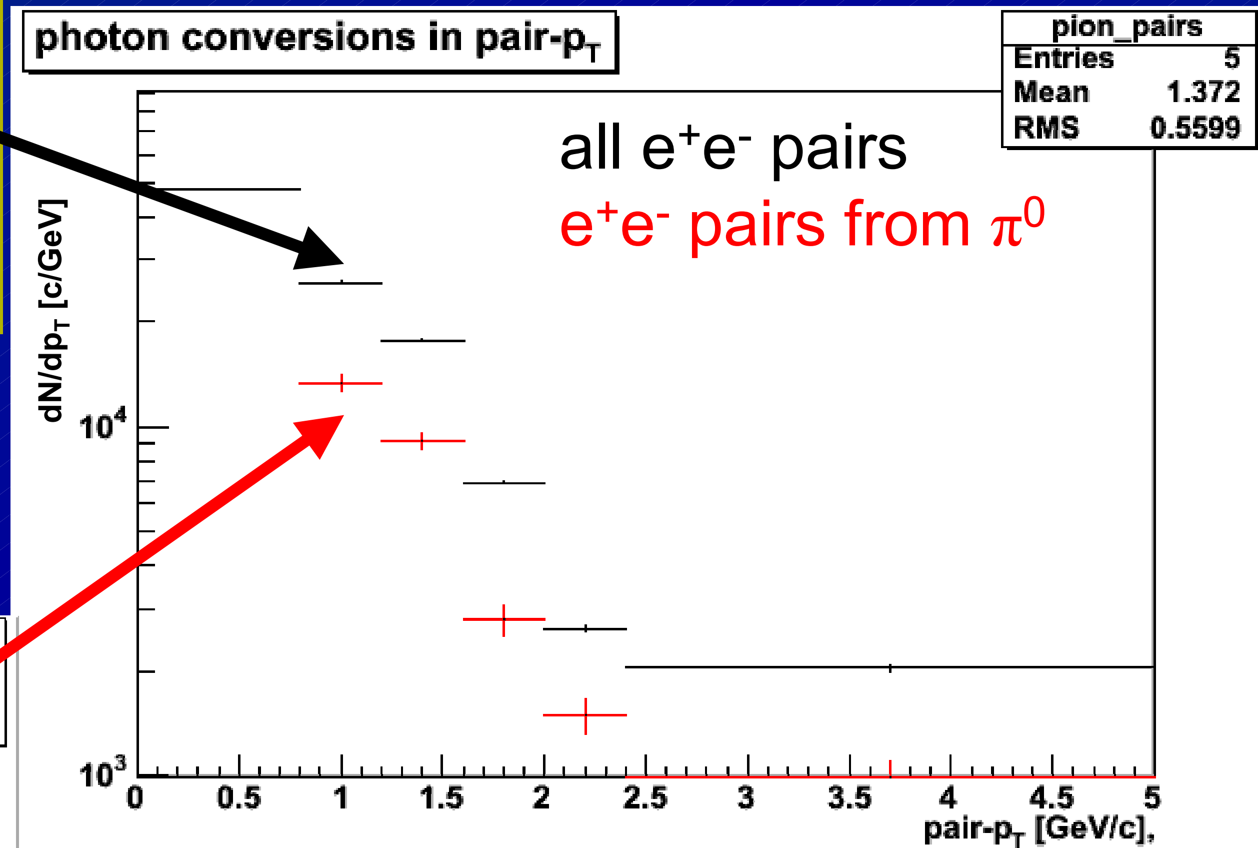
Let's find photons in the EMCal and pair them…

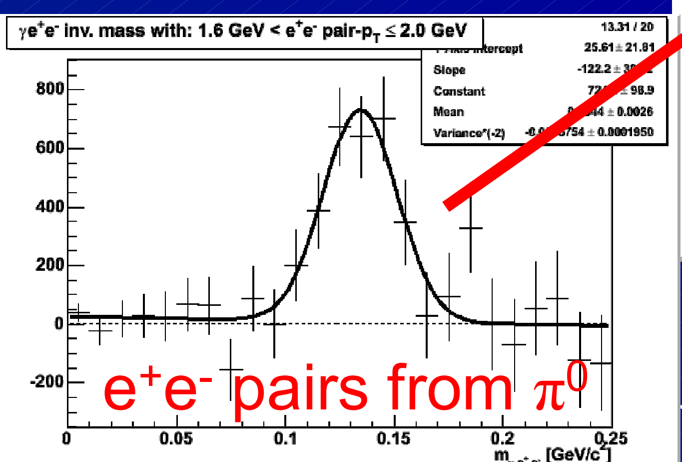
π^0 signal extraction



$N_\gamma^{incl}(p_T)$ and $N_\gamma^{\pi^0\ tag}(p_T)$

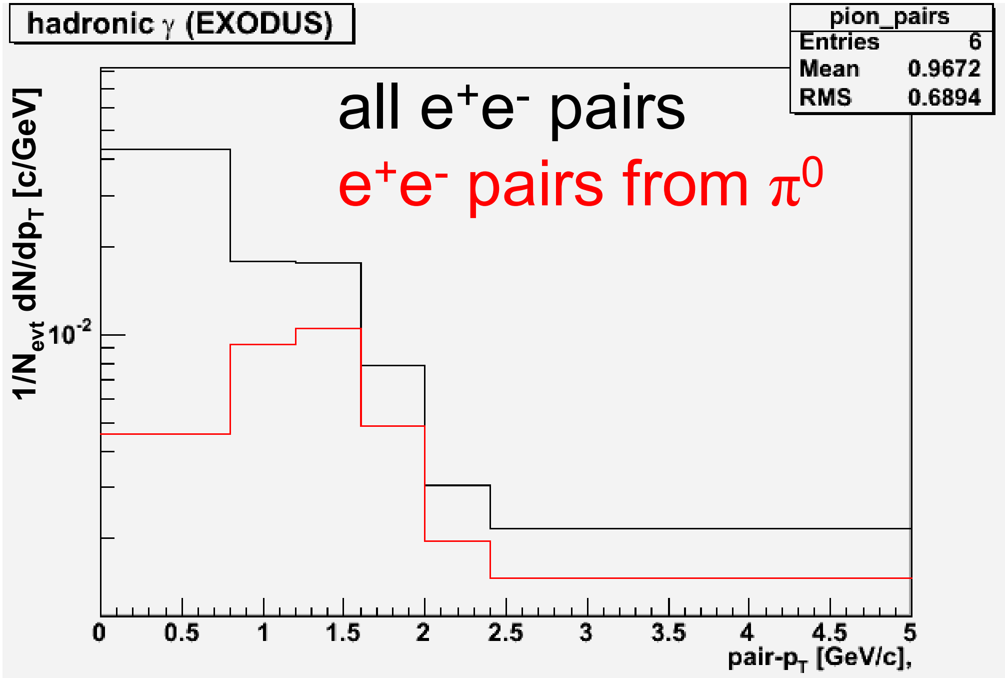




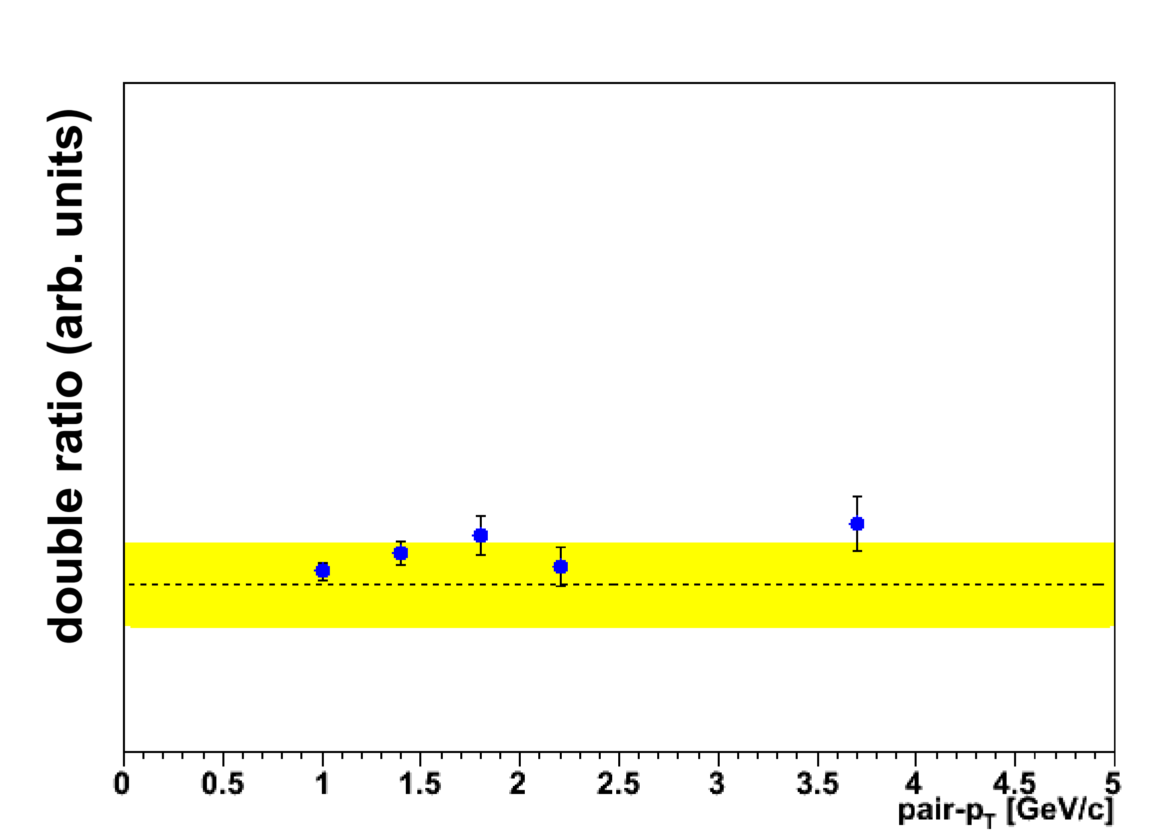


Simulations: $N_\gamma^{hadr}(p_T)$ and $N_\gamma^{\pi^0\ tag}(p_T)$

- Inclusive photon spectrum
  - $\pi^0, \eta \rightarrow \gamma e^+e^-$
    - π^0 parameterization from measured data
    - η from m_T scaling, yield normalized at high p_T (0.45 from measurement)
  - Use Dalitz decay ($\pi^0 \rightarrow \gamma\ \gamma \sim \pi^0 \rightarrow \gamma\ \gamma^* \rightarrow \gamma e^+e^-$ for $p_T > 0.8$ GeV/c)
- All e^+e^- (from π^0, η) in the acceptance → p_T spectrum of e^+e^-
- If γ from π^0 is also in acceptance
  →p_T spectrum of e^+e^- from π^0



$(N_\gamma^{incl}(p_T)/N_\gamma^{\pi^0\ tag}(p_T))\ /\ (N_\gamma^{hadr}(p_T)/N_\gamma^{\pi^0\ tag}(p_T))$



Systematic uncertainties:

- conversion background 6%
- π^0 background 20%
- reconstruction efficiency 3%
- agreement of conditional acceptance 10%

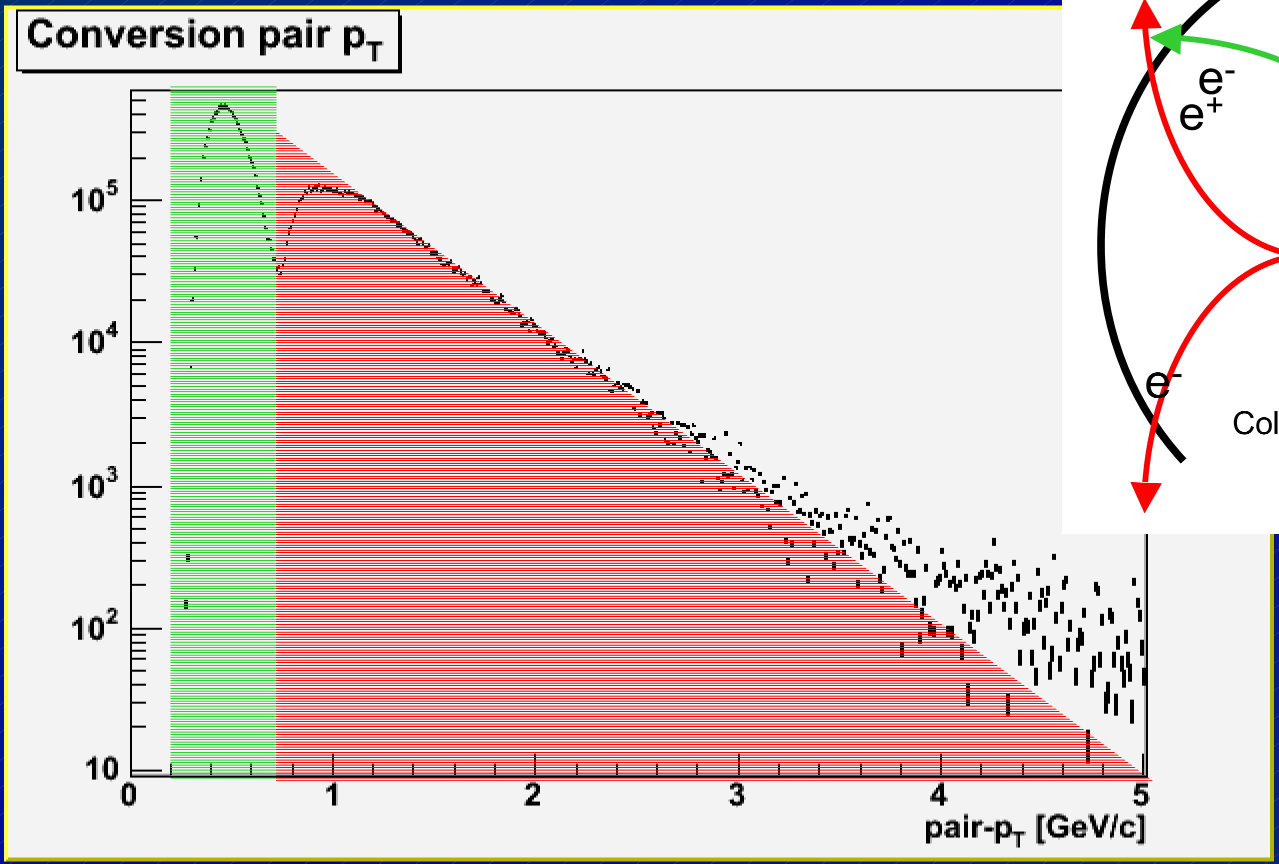
→ total: ~25%

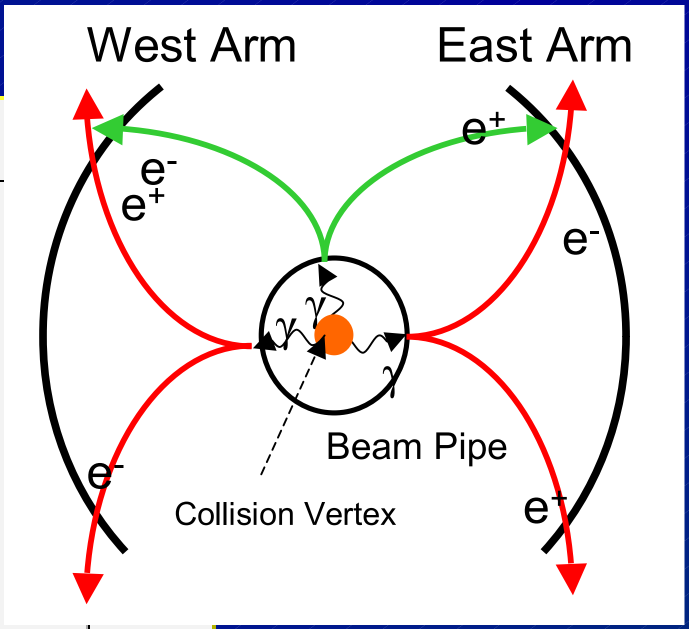
Summary

- A new method to measure direct photons has been present
- We can extract a clear photon conversion signal from beam pipe conversions
- We successfully reconstruct π^0
- Need to reduce systematic errors

Backup

Conversion pair-pT distribution



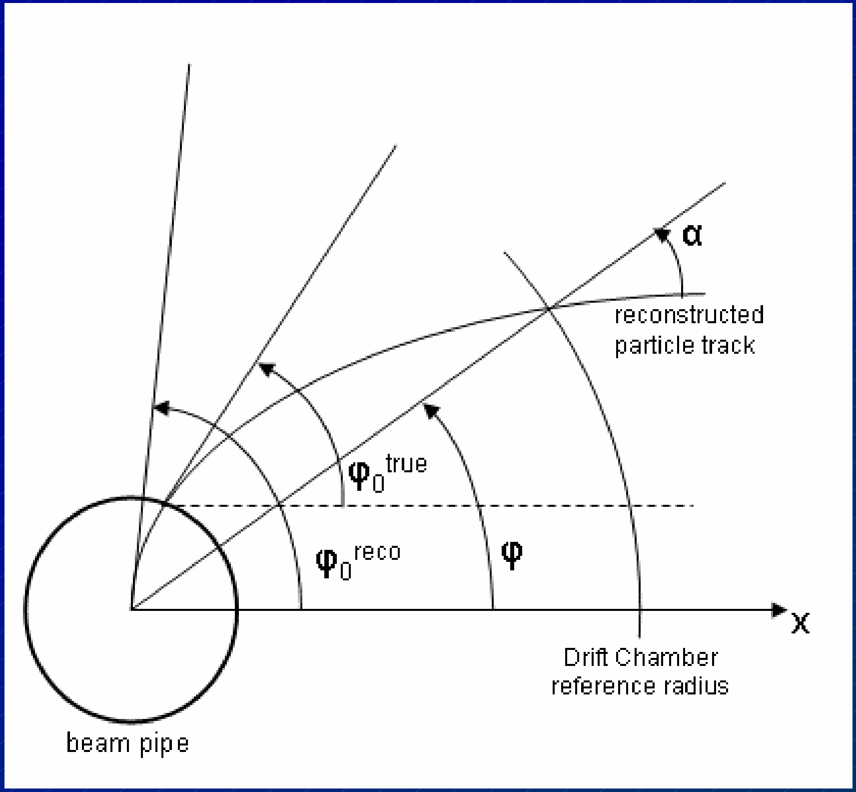


- In principle we reconstruct photons down to p_T ~ 400 MeV/c
- The π^0 reconstruction reaches limit at 800 MeV/c due to acceptance effects

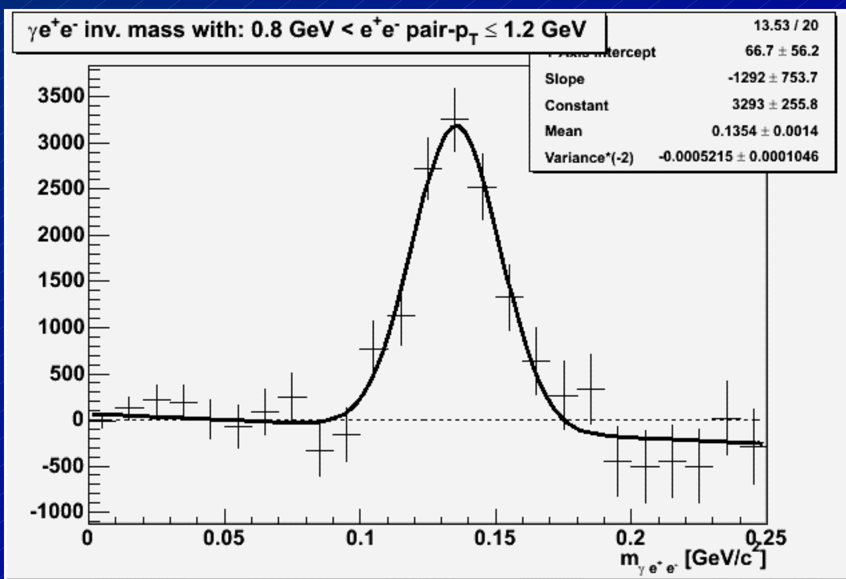
Beam Pipe Conversions

- Track reconstruction relies on $\int \text{Bdl}$
- $\int_r^\infty \text{Bdl} < \int_0^\infty \text{Bdl}$

  $m_{inv} = \sqrt{2}\langle p \rangle \sin(\vartheta)$
- Pair obtains additional opening angle
- Pair gets mass > 0
- Inv. Mass proportional to distance from collision vertex
- → conversion peak shifts w. r. t. to Dalitz decays

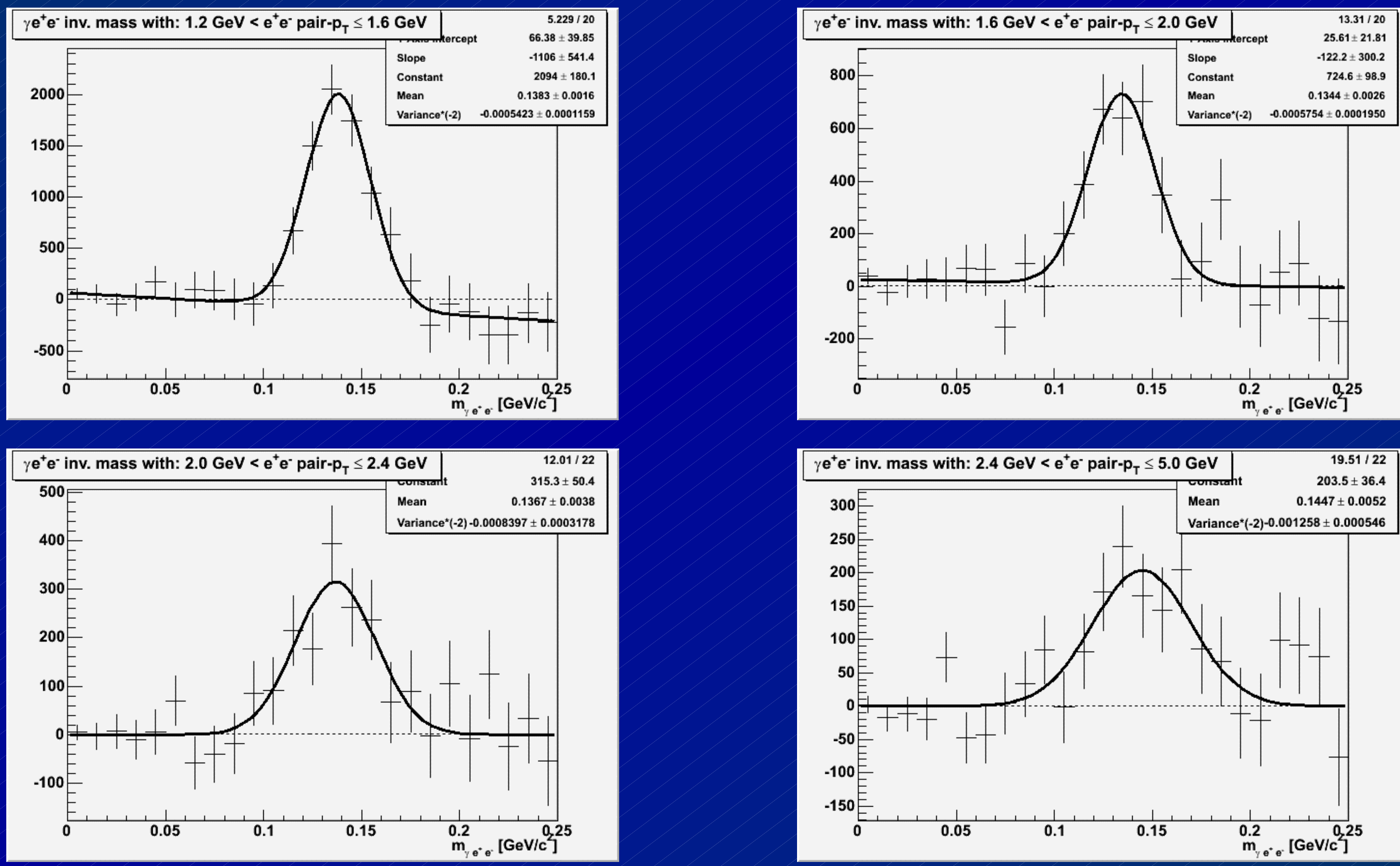


Subtracted inv. mass spectra

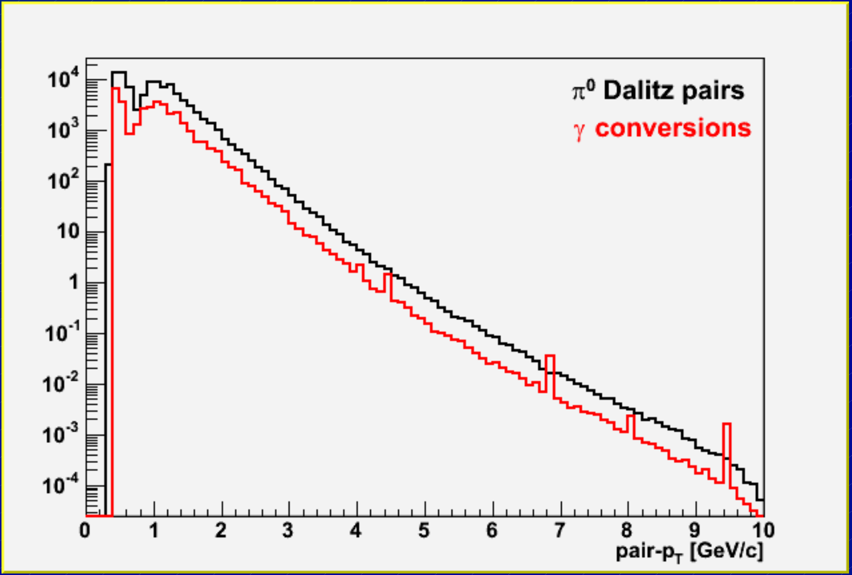


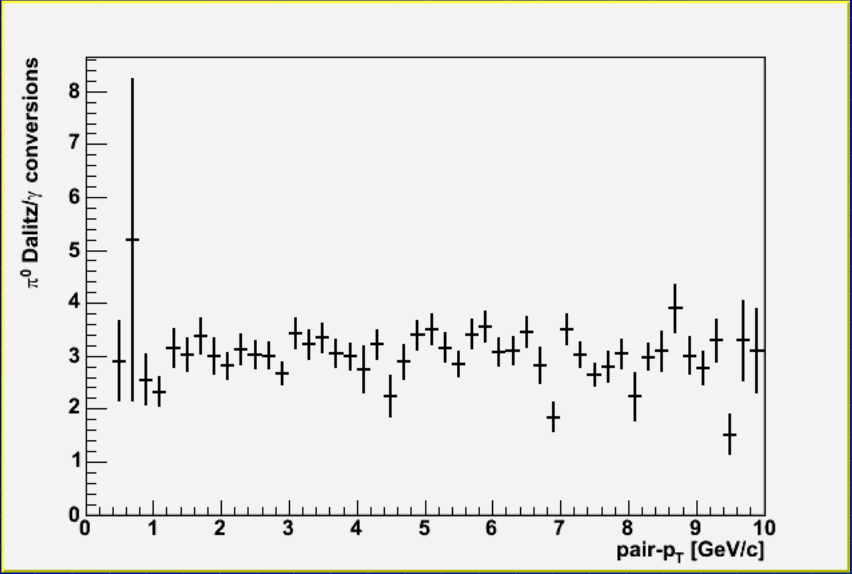
- e^+e^- pair-pT bins [GeV/c]:
  - $0.8 < p_T \leq 1.2$
  - $1.2 < p_T \leq 1.6$
  - $1.6 < p_T \leq 2.0$
  - $2.0 < p_T \leq 2.4$
  - $2.4 < p_T \leq 5.0$

Subtracted inv. mass spectra



Comparison: Dalitz - Conversions

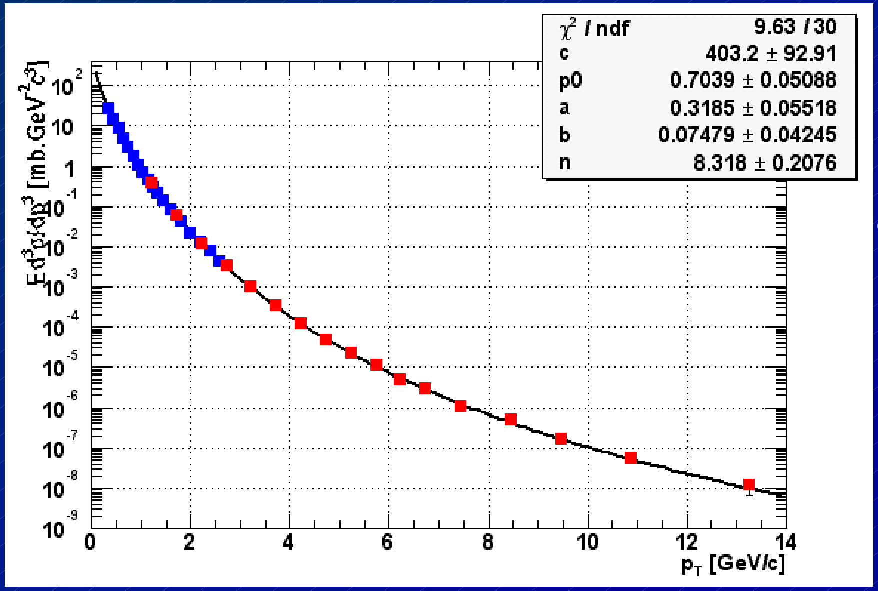




Cocktail ingredients (pp): π^0

- most important: get the π^0 right (>80 %), assumption: $\pi^0 = (\pi^+ + \pi^-)/2$
- parameterize PHENIX pion data:

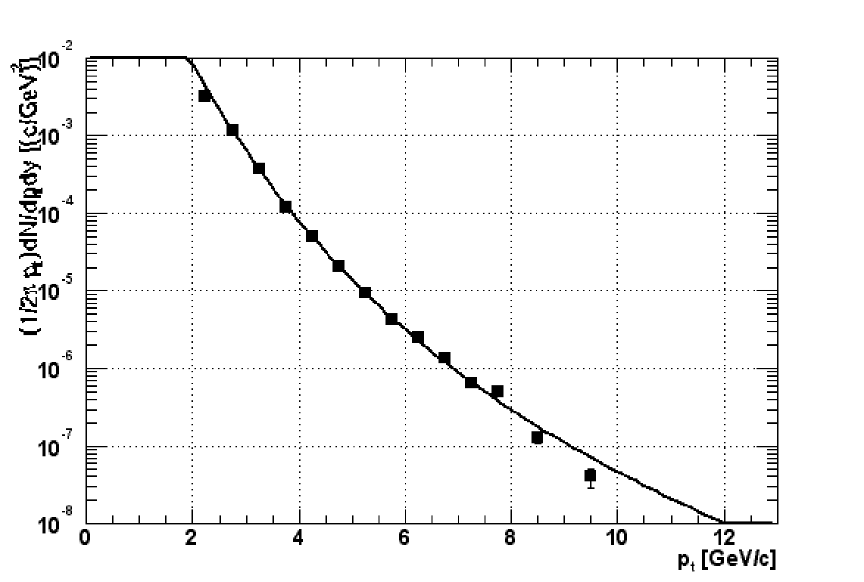
$$E\frac{d^3\sigma}{d^3p} = \frac{c}{\left(\exp(-ap_T - bp_T^2) + p_T/p_0\right)^n}$$



- most relevant: the η meson (Dalitz & conversion)
- also considered: ρ, ω, η′, φ
- use mT scaling for the spectral shape, i.e.

$$p_T \rightarrow \sqrt{p_T^2 + m_{meson}^2 - m_\pi^2}$$

- normalization from meson/π^0 at high pT as measured (e.g. $\eta/\pi^0 = 0.45 \pm 0.10$)



Tagging efficiency